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A MICROECONOMETRIC CHRONICLE OF THE GREEN REVOLUTION

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I. INTRODUCTION

Only a short while ago it was commonplace for the most distinguished social scientists to regard peasants in the less developed agricultures as bound by culture to traditional agricultural practices, unable or unwilling to respond to commercial incentives that have been the driving force behind western economic development.[1] During the past decade a quite different view has all but replaced this position: a series of econometric investigations has confirmed T.W. Schultz' contention that traditional patterns are maintained because peasant farmers are economic men in the same sense as their western counterparts and, faced with economic incentives, will respond in a manner predicted by economic theory.[2]

Our own work on agricultural development in the less developed countries began with a case study of the Indian Punjab. We commenced this study with an extensive tour through the region. We tramped through villages and farms, interviewed farmers and discussed agriculture, with experts at Punjab Agricultural University, and in the State and Federal

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**Ohio State University and the University of Wisconsin, respectively.

governments. These direct observations and depth interviews, augmented by a survey of secondary statistics, yielded the apprehension of a state in rapid transition from age-old production methods to modern technology, a rapid growth in farm output, and a drastic change in the seasonal work pattern of farmers. The transformation clearly involved extensive investments and the substitution of capital for labor as various individual tasks were being mechanized, and as wholly new methods and materials were being adopted.

Confronted with these empirical facts and encouraged by the findings that economic analysis might aid one in understanding them we set out to construct a simulation model that would enable us to describe the process of agriculture in transition and that would make possible useful projections of the sector's likely future course under various economic policies designed to promote its future development. In specifying the model structure we attempted to incorporate explicitly the microeconomic details that appeared to be a strategic part of the revolution in vivo that we had seen in our travels, strategic details of farm decision making, of technology and of market structure. We also based it on the hypothesis of economic rationality modified to account for the realities of practice in the field. The model when completed was used to simulate the detailed history of crop production, physical and financial investment, and of resource utilization during the period 1952 to 1965.

Our first task was to test the model for its veracity. To accomplish this we compared its "predictions" with published statistics wherever available. A detailed account of this exercise is reported in a paper entitled, "A Microeccnometric Study of Agricultural Development," DAY and SINGH [1971]. Our conclusion was that the model "works," that it is indeed

capable of approximating past developments. From this we inferred that it could be used to project possible future developments, and what shall especially concern us here, that it could augment our understanding of the process of change by presenting a detailed, quantitative chronicle of the farm activities as they must have occurred.

The present paper presents this chronicle, traced by the model, for the period 1962-1965, focusing on productivity, capital utilization, employment, technological change, factor substitution, commercialization and mechanization. We conclude with our inferences about the nature of development and some speculation about its future course. Then we allow ourselves to extrapolate from this specific case study to the process of sector development as it might be expected to occur elsewhere. We also speculate on the problems that might come to dominate agricultural development policy in the future.

II. THE MODEL[3]

Farms in the Punjab engage mainly in the production of field crops both for home consumption and commercial sale. They are fairly homogeneous with respect to soil, climate, topography, farm size, resource distribution and tenure conditions. Field crops are sown in two cropping seasons, winter (rabi) and summer (kharif). Rabi crops include wheat, gram, barley and green winter fodders, mainly Egyptian and Indian clovers; Kharif crops include cotton, maize, rice, groundnut and bajra or spiked millets. Along with sugar cane, whose culture extends through both seasons, these crops accounted for over 96 percent of the total cropped area in the state. The production of these crops is the focus of our model under traditional and

modern farm practices, under irrigated and nonirrigated conditions, with traditional varieties and, for wheat, cotton, maize, rice and bajra, with new and improved varieties of seed.

The model is made up of seven basic components: (1) a set of farm activities representing decision variables for farms within the region; (2) an annual objective function measuring the expected revenues from crop sales, the costs of purchased inputs and annual investment charges for resource augmenting investments; (3) a technology matrix representing the traditional and modern input-output structure of home and cash consumption, farm production, investment, sales, purchase and financial activities; (4) "technial" constraints representing regional resource and financial limitations; (5) "behavioral" constraints representing adaptive, "safety-first" limitations for protection against mistakes of cropping and investment choices, and representing drags on investment due to "learning" and "unwillingness to change"; (6) feedback functions that relate the parameters of the current programming problem to previous decisions; and (7) exogenously given input and output prices, regional supplies of land and labor resources and exogenously estimated subsistence and cash consumption requirements.

These components are designed to represent the following hypotheses or principles of farm decision making.

(1) Farmers first determine subsistence needs; (2) they than determine desired cash consumption based on current cash income and forecasted return on savings. (3) Farmers attempt to distribute marketing risk by choosing a "portfolio" of crops. Changes in the "portfolio" are limited by "rule of thumb" percentages that approximate more sophisticated risk programming models; (4) they also limit investments in a given capital good according to a flexible accelerator type of bound to limit risks of investing "too

much"; (5) their willingness to adopt new practices is related to exposure and this can be measured by the current amount of production already involving the new practice; (6) anticipated prices are based on recent market experience. (7) Given these considerations farmers allocate their available resources so as to maximize anticipated net cash returns from farming.

The model is computed by setting up and solving a linear programming problem for a given initial year. A new set of limitation and constraint coefficients is then computed by substituting the optimal solution vector just obtained and exogenous data or trends into the feedback functions. A new objective function is obtained by substituting past prices in the price forecasting equations and the new linear programming problem is set up and solved for the next year. The complete model consists of this sequence of recursively connected linear programming problems. It assumes that farm behavior is generated by a sequence of "rolling plans" or "recursive programs" rather than by the optimal strategy derived from a long horizon, dynamic programming or optimal control model.

III. THE MODEL'S CHRONICLE

The recursive linear programming model just described was used to simulate the recent agricultural history of the central districts of the Indian Punjab over the 14 year period from 1952 to 1965. On the basis of elaborate statistical tests the model was found to reproduce rather well the most salient features of the recent economic development in Punjab agriculture. Having satisfied ourselves on this account we use the model here to provide a detailed quantitative chronicle of this green revolution. We have presented this chronicle graphically in terms of various indexes of outputs,

inputs and productivity. These graphs are shown on succeeding pages. The indexes on which they are based are contained in a data supplement that can be obtained from the authors upon request. It must be remembered that we are using the model here to derive a detailed, definitive picture of recent economic history, a picture that can otherwise only be sketched in vague, imprecise terms on the basis of piecemeal data.

1. Aggregate Farm Output, Input and Productivity

Figures 1 to 4 display the model estimated history of total farm output, marketed surplus, average factor productivities, aggregate input uses and new power sources. These indexes outline in the broad terms the green revolution as it occurred in the Punjab: the rapid rise in output and factor productivity and the commercialization implied by a growing marketed surplus and explosive adoption of nonfarm inputs.

Aggregate output doubled during the period, a result achieved at a 7.8% annual growth rate. Marketed surplus tripled for the period with an annual growth rate of 15¢. These trends were accompanied by a 90% increase in output per cultivated acre and a 50% increase in output per unit of capital outlay. The underlying changes in input use display a mixed pattern, with the greatest increases evident in nonfarm produced, nontraditional inputs (tractors, nitrogenous fertilizer) and with only moderate increases (land, labor, water) or decline (bullock labor) in traditional inputs.[4]

2. Mechanization

What has only recently begun to receive attention, however, is the rapid mechanization of the sector. According to model estimates (Figure 4) the number of tractors in use increased over sevenfold, the number of tubewells nearly twelvefold and the number of power threshers over four-

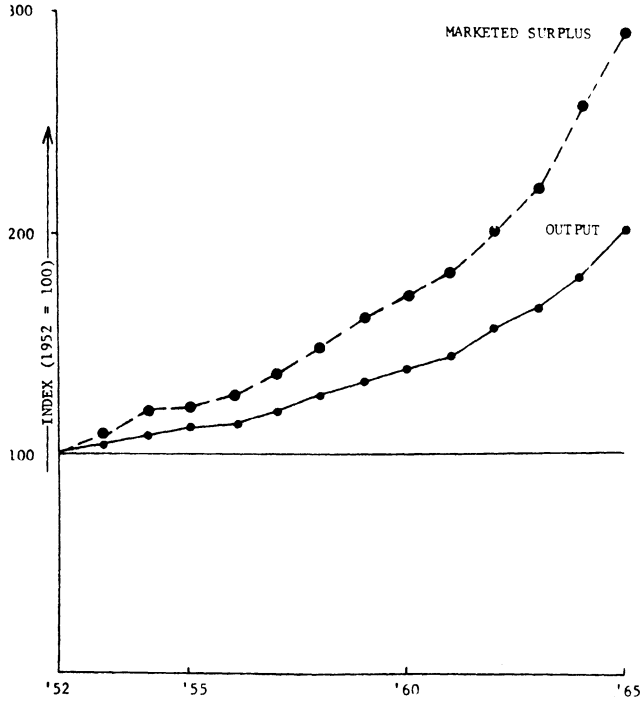


FIGURE 1: MARKETED SURPLUS AND TOTAL OUTPUT

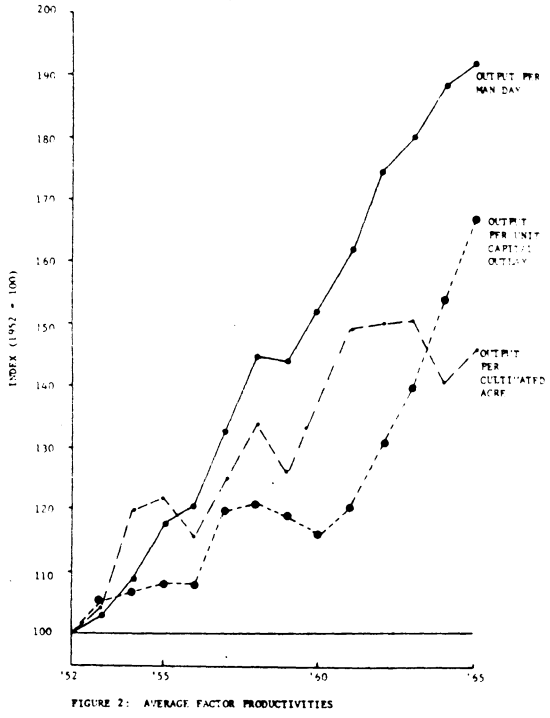


FIGURE 2: AVERAGE FACTOR PRODUCTIVITIES

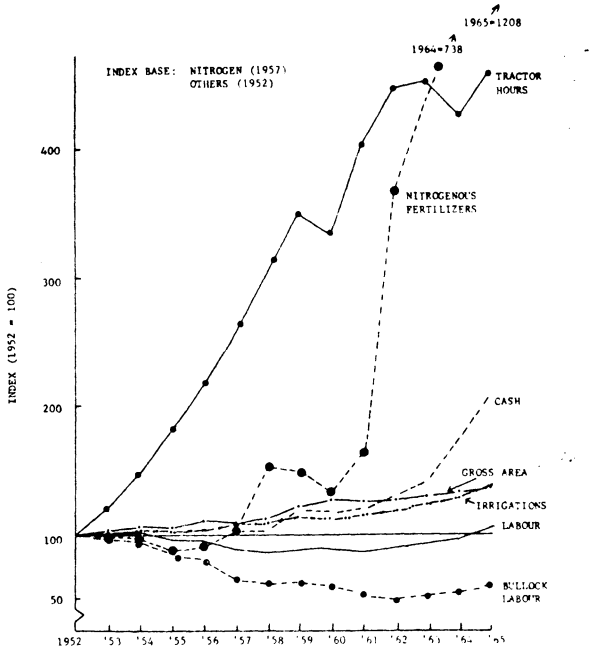


FIGURE 3: ANNUAL USE OF VARIOUS INPUTS

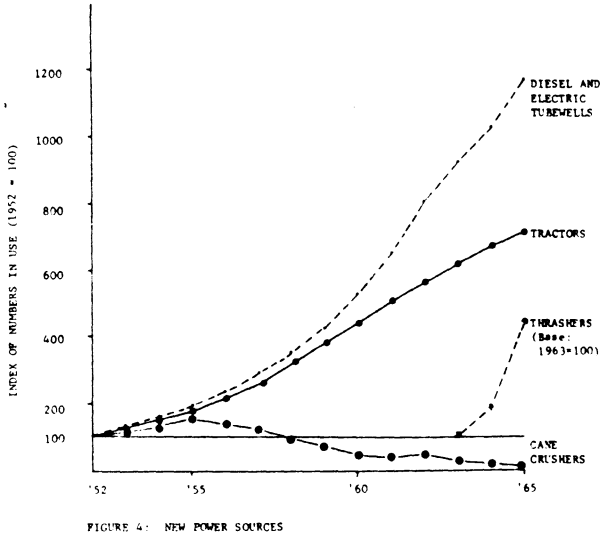


FIGURE 4: NEW POWER SOURCES

fold, even though the latter became widely available in the region only in 1963. These results appear to be very close to the actual number of these new power sources in use,[5] except in the case of cane crushing equipment where the model substantially underpredicts investments and consequently the number in use.[6]

An important feature of this rapid mechanization process, brought into sharp focus by the model results shown in Figure 5, is its task specificity. The choice with regard to technique is made task by task. During the period studied, investments in nonfarm produced capital goods have been concentrated on tractors for land preparation, sowing and transportation, tubewells for irrigation and power threshers for threshing winter crops. As a corollary the traditional bullock and labor intensive practices are being rapidly replaced for these specific tasks, while other tasks continued to be performed in the traditional manner.[7]

3. The "Seeds of Change" and Fertilization

The introduction and adoption of new high yielding varieties in the Punjab is less than a decade old and already their impact on yields has been impressive.[8] Most of the new varieties became available to farmers in the region only in the last six years of the period for which the model was simulated, and chemical nutrients distributed were negligible before 1957. Hence, the results to 1965 do not bring out fully the overall impact of their adoption during the past seven years. However, the model does capture the "take off" of the biological revolution: the so-called new "seeds of change."

Figure 6 displays the progress in the use of new seed varieties of maize, wheat, rice and bajra from 1957 to 1965. The model clearly explains

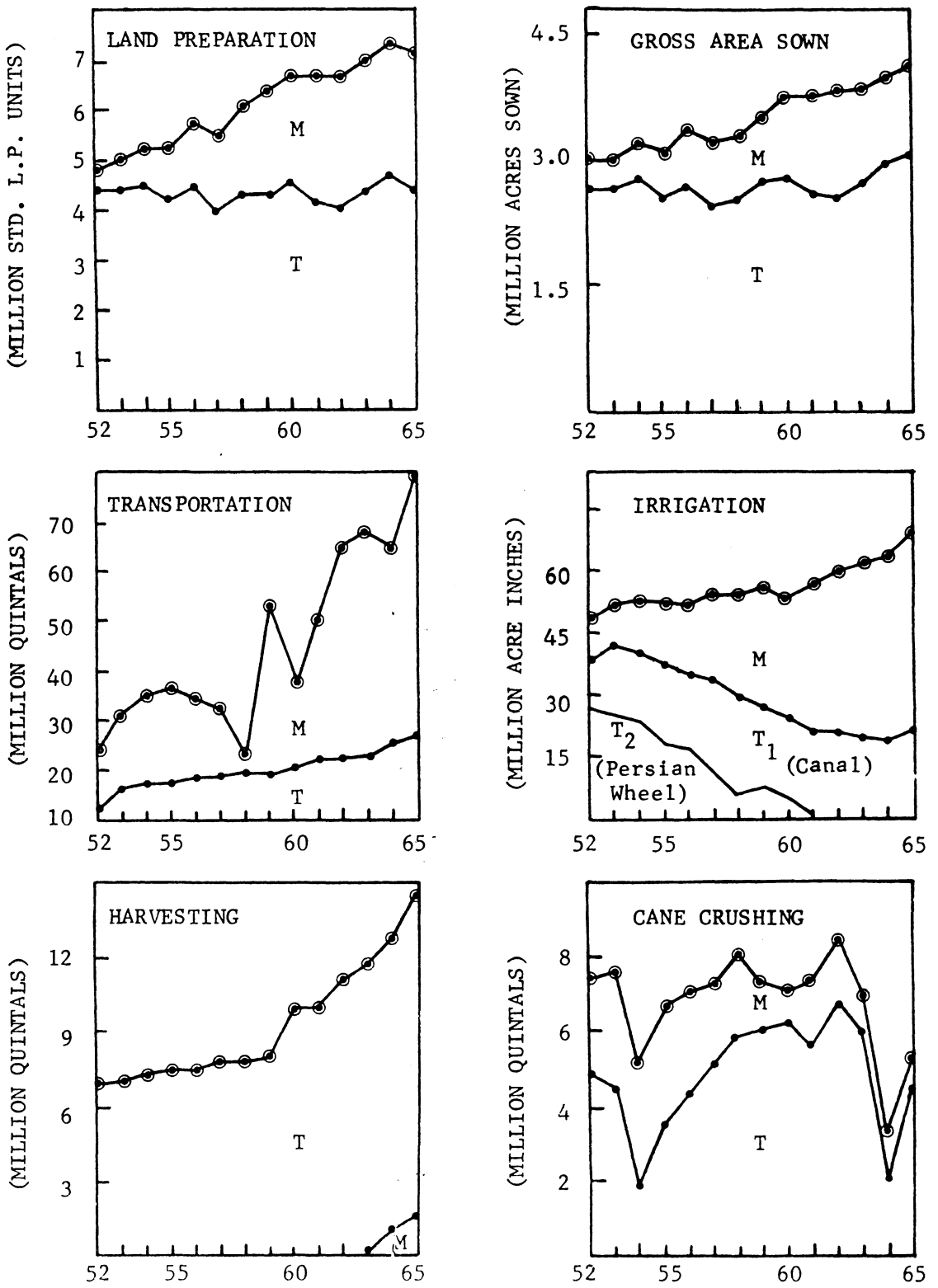


FIGURE 5: PERFORMANCE OF VARIOUS TASKS BY MODERN (M) AND TRADITIONAL (T) TECHNOLOGIES

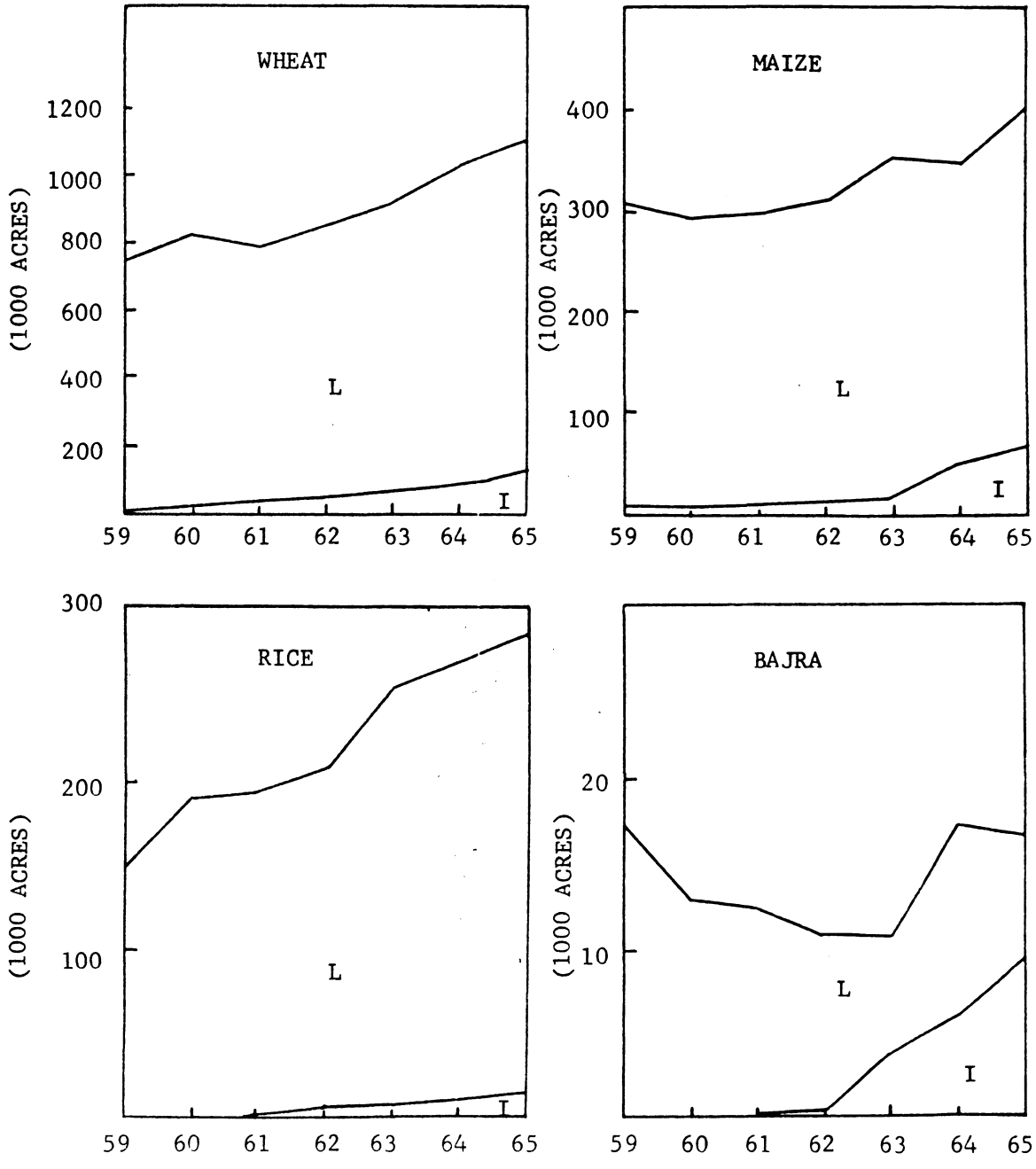


FIGURE 6: IRRIGATED ACREAGE PLANTED TO LOCAL (L) AND IMPROVED VARIETIES (I) FOR MAJOR CROPS

the remarkable, and by now well known, impact of varietal change, especially for wheat. These varietal changes were closely associated with changes in total acreage fertilized for various crops. According to our estimates total nitrogen use increased over twelvefold to a level of 57 million kilograms by 1965; phosphorus use increased fifty-three fold to a level of 3.9 million kilograms. The total acreage of all crops fertilized increased fourfold from 1952-1965. On the basis of model evidence it seems clear that new crop varieties are so profitable under fertilization that once they were introduced and planted, the entire area planted was under some fertilization, bearing out the contention that new crop varieties are complementary to fertilizer inputs. The general tendency after 1962 when nitrogenous fertilizer supplies were doubled was to fertilize all the acreage sown under irrigated conditions for the crops that would take fertilization. The combined impact of new varieties and increased fertilization upon crop yields under average weather conditions is shown in Figure 7.[9]

4. Market Linkage and Commercialization

As we have already noted the model describes the increasing commercialization of the farm sector in the Punjab by explaining the growing demand for nonfarm produced capital and variable inputs and by tracking its increasing commercial orientation on the supply side: the increasing disposal of food off the farm instead of in the home. The increasing forward linkage is shown in Figure 8 which presents indexes of sales, production and home consumption for five major crops. The increasing backward linkages with markets through the demand for nonfarm inputs are evident in the growth of cash outlays on various nonfarm produced goods, both in absolute terms

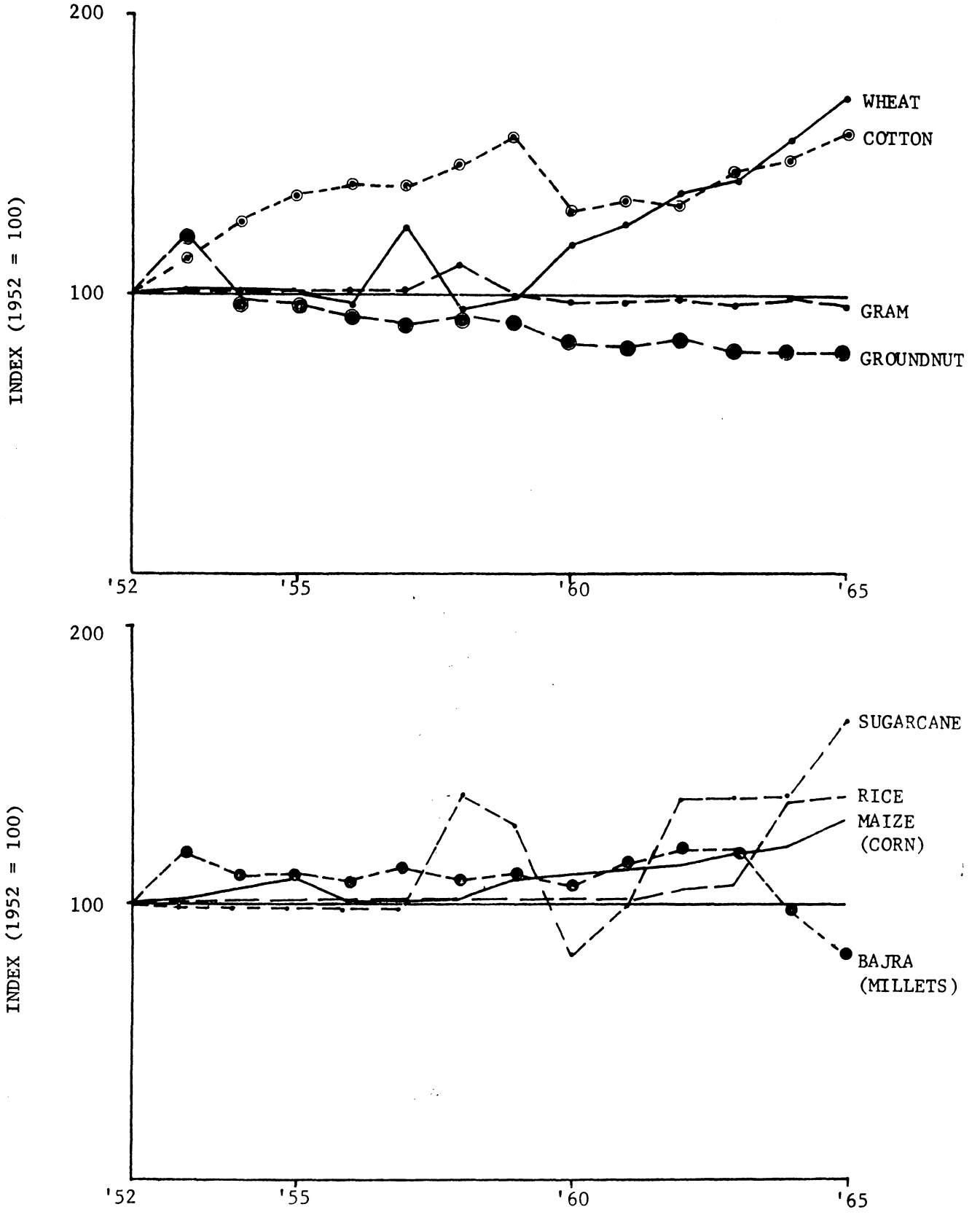


FIGURE 7: AVERAGE YIELDS FOR VARIOUS CROPS FOR AVERAGE WEATHER

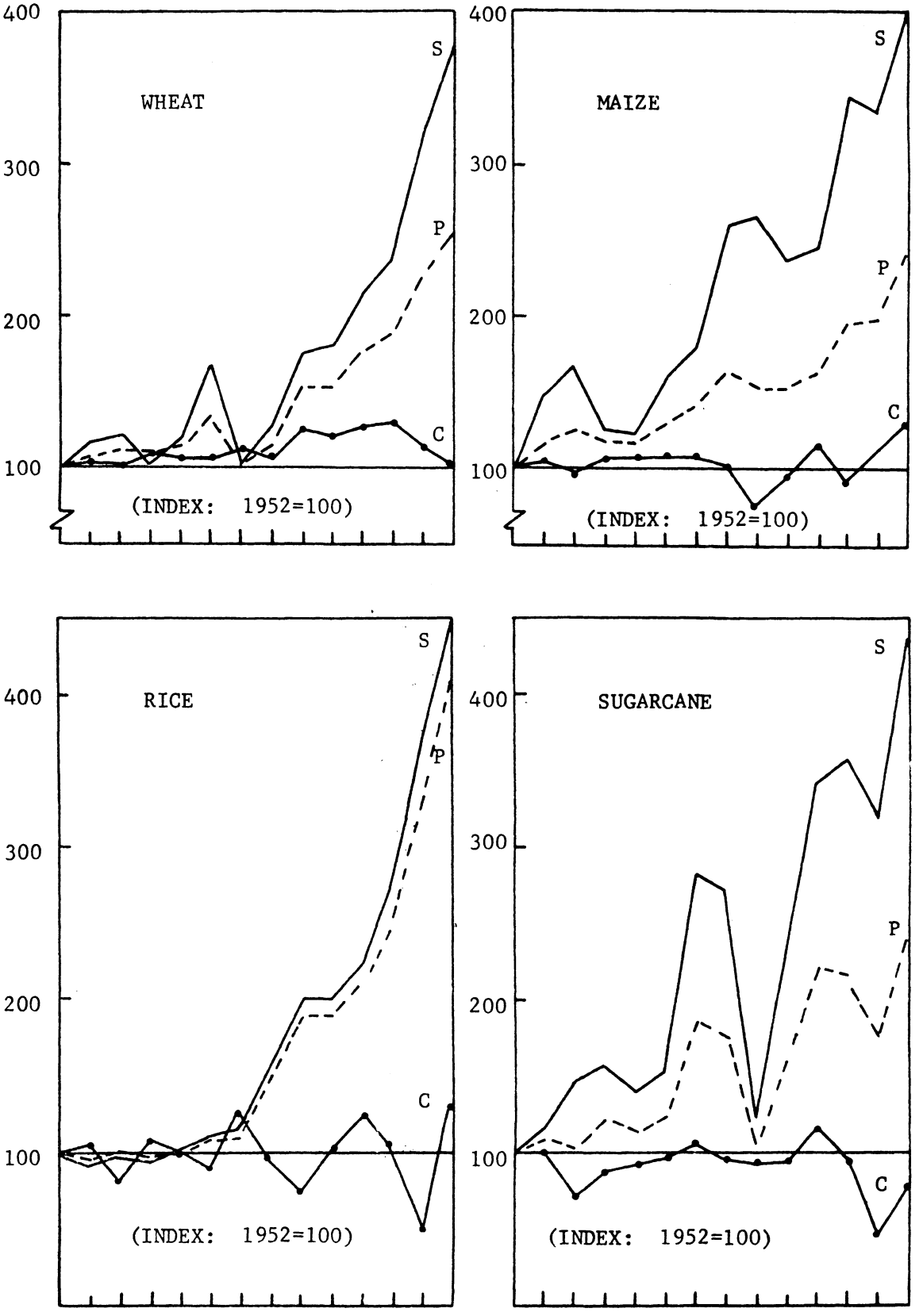


FIGURE 8: INDICES OF MARKET SALES (S), PRODUCTION (P) AND RETAINED CONSUMPTION (C) FOR SUBSISTENCE CROPS

and as a percentage of total cash outlays. We shall look at these in some detail in subsection six below.

5. Derived Demand for Labor

The model estimates the composite impact on farm sector labor utilization of two conflicting forces: a reduction in the demand due to the adoption of task specific labor saving technologies and at the same time an increase in the demand for labor due to the increase in yields and total output as a result of increased double cropping, increased area sown to high yielding varieties and the use of chemical nutrients. The net effect on total annual and seasonal labor use shown in Figure 9 is a decline after 1952; a leveling off after 1957; and a sharp increase after 1961, coinciding with a rapid rise in output. By 1965 total labor use was 5 percent higher than in 1852 in spite of the rapid mechanization described earlier.

However, on the basis of these annual aggregate estimates anywhere from 36 to 52 percent of the total labor force and 17 to 37 percent of the family labor force was estimated by the model to be "surplus" or "redundant" in the region over the period.

This impression of annual labor "surplus" fails to account for the seasonal distribution of labor use. This more detailed aspect of structural change is graphed in Figure 10. It contrasts markedly with the annual data. Labor use increased substantially in period I when summer crops are planted, period VI when winter crops are harvested and threshed and period VII when winter crops are transported and land has to be prepared for summer planting. In other periods labor use increased only moderately: period II when summer crops are irrigated and period III when land is prepared for winter planting. But labor use declines in period IV when

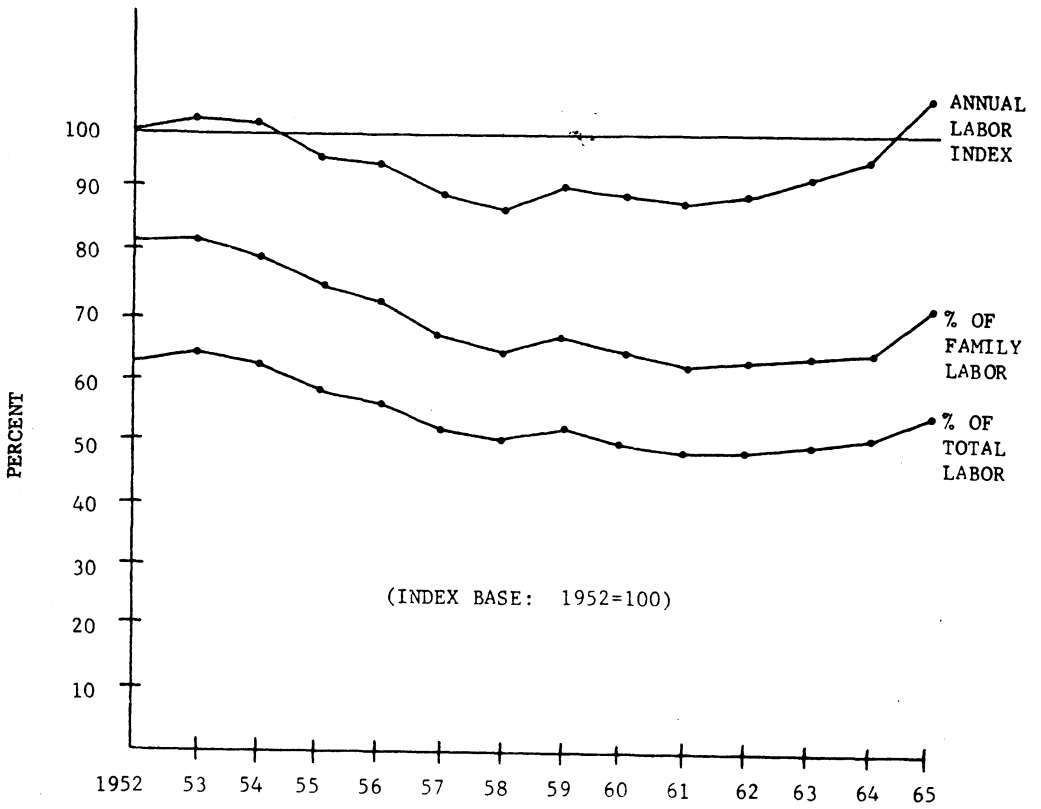


FIGURE 9: INDEXES OF ANNUAL LABOR USE AND LABOR SURPLUS

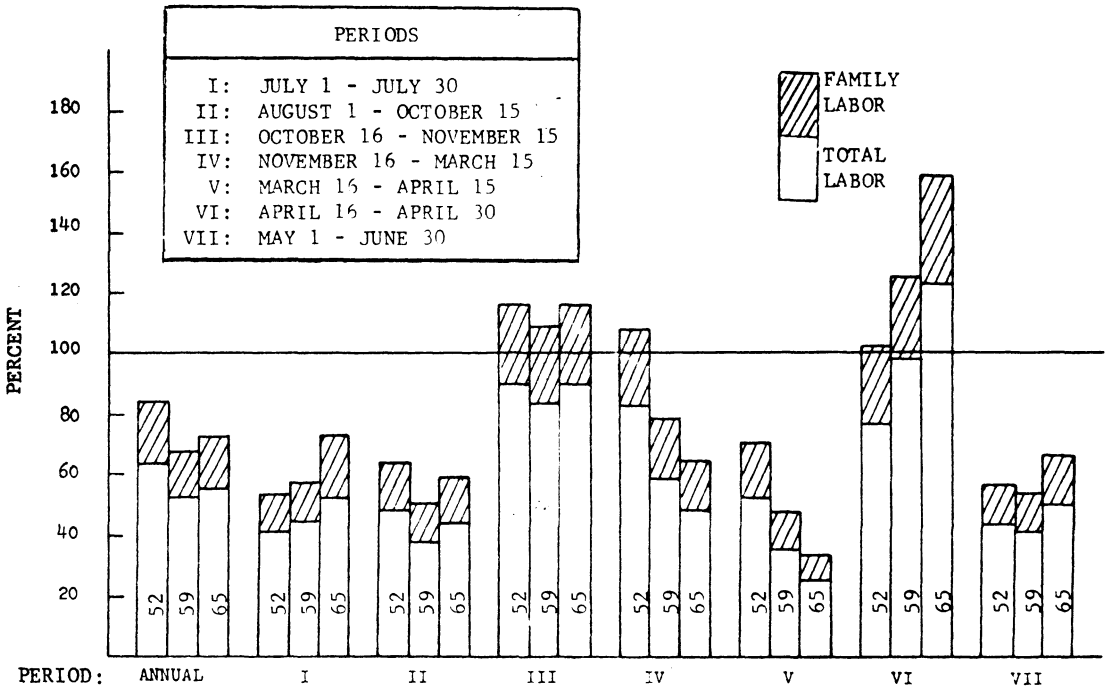


FIGURE 10: LABOUR USE AS A PERCENTAGE OF TOTAL AND FAMILY LABOUR AVAILABLE

summer crops are harvested, and sugarcane processed and in period V when winter crops receive most of their irrigation. To summarize, the model estimates a drastic structural shift in the seasonal demand for labor.

How has this structural shift affected underemployment and labor scarcity? The model's answer is shown graphically in Figure 11. Instead of a chronic labor surplus one finds a picture of seasonal scarcity. The model shows family labor is "very scarce" in some periods (III and VI), "occasionally scarce" in others (IV), "slack" in some (I, II, and VII) and "very slack" in others. In periods III and VI, when labor is very scarce and family labor is exhausted, labor has to be hired in order to perform all the tasks. The seasonal scarcity explains in part why technological change is task oriented and why mechanization occurs in an apparently labor surplus economy. Though the demand for total annual labor has increased only slightly, changes in the cropping patterns and the technological mix have increased the demand for labor substantially in some periods and reduced it substantially in others.

6. Financial Flows[10]

The model estimates of financial flows from the farm to the nonfarm sector are shown in Figures 12-15. Figure 12 displays total cash payments for nonfarm inputs and its relation to labor utilization, land utilization and output. The substitution of "capital" in the form of off-farm inputs for land and labor is clearly evident.

A changing composition of cash use is shown in Figures 13 and 14. Total cash outlays on both capital goods and variable inputs increased substantially through 1961, but after that year the share of total cash allocated to variable inputs continues to increase, while the share

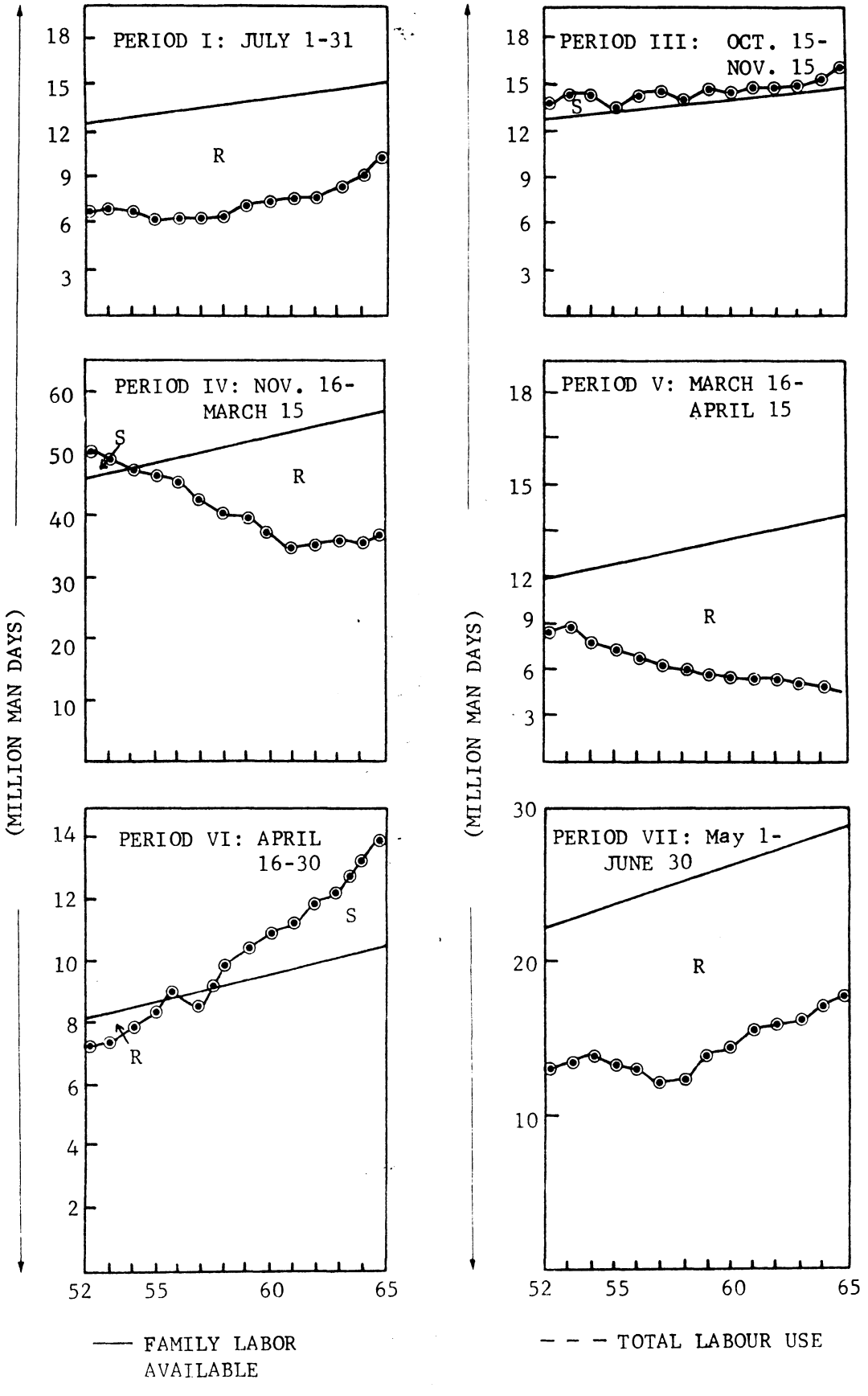


FIGURE 11: SEASONAL FAMILY LABOUR SCARCITY (S) AND REDUNDANCY (R)

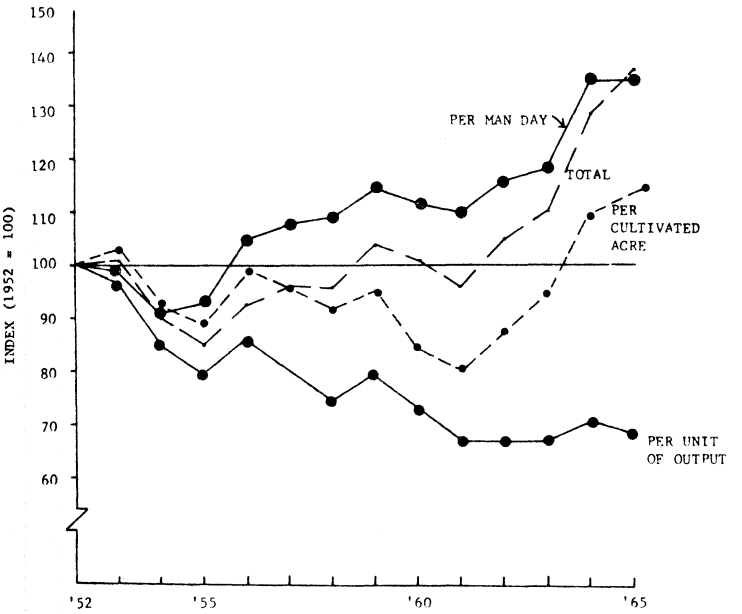
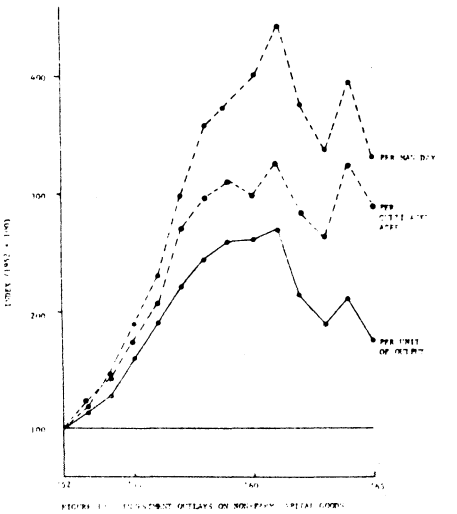
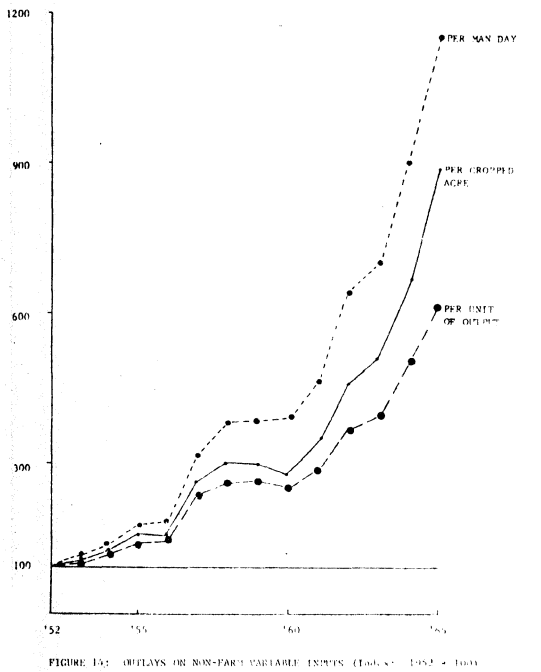
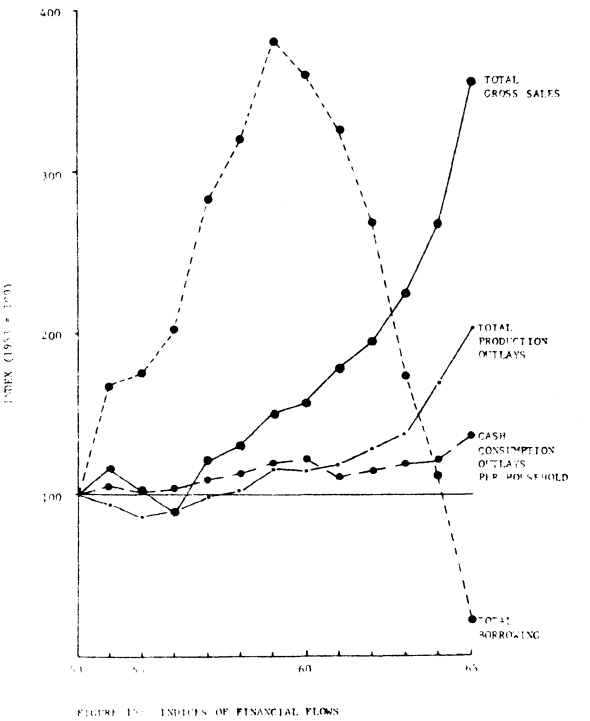


FIGURE 12: TOTAL CASH OUTLAYS (In Constant 1952 Prices)







allocated to capital goods tapered off. Total farm capitalization, however continued unabated. The growing importance of nonfarm inputs, as shown by the model, confirms the story of increasing dependence of the agricultural sector on backward market linkages.[11]

So far we have examined the items on which financial outlays have been made. Now we direct ourselves in Figure 15 to the sources from which this financial capital was forthcoming. Between 1953 and 1959 an increasing part of the total cash requirements were met by borrowings, a period that saw a dramatic increase in short term borrowing. After 1960, however, the picture changes and increasing outputs, crop sales and cash incomes from these sales allow the farmers to reduce their debts so that by 1965 only about 3 percent of the total cash requirements were met through borrowings (as compared to 53 percent in 1959) and annual short term borrowing declined to Rs. 22.7 million (from Rs. 403.7 million in 1959). Thus, within a period of five years after the introduction of new varieties and increased distribution of nutrients, increases in output were large enough to make farmers nearly self-reliant for their capital requirements, even though both production and consumption expenditures continue to increase.

7. Factor Proportions

As we have already seen, the vast structural changes that took place in the Punjab were reflected in changing factor proportions and productivities. A more detailed picture of this structural transformation is shown in Figures 16-18 which display respectively various input-output ratios, input-land ratios and input-labor ratios. We see that land, labor and financial capital use per unit of output declined, while machine use per unit of output increased, as it replaced the use of animal draft. As

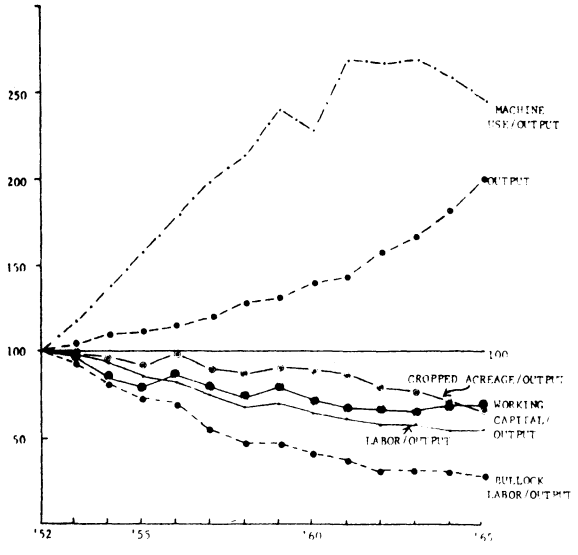


FIGURE 16: INDICES OF INPUT TO TOTAL OUTPUT RATIOS IN CENTRAL PUNJAB, 1952-65 (Base: 1952 = 100)

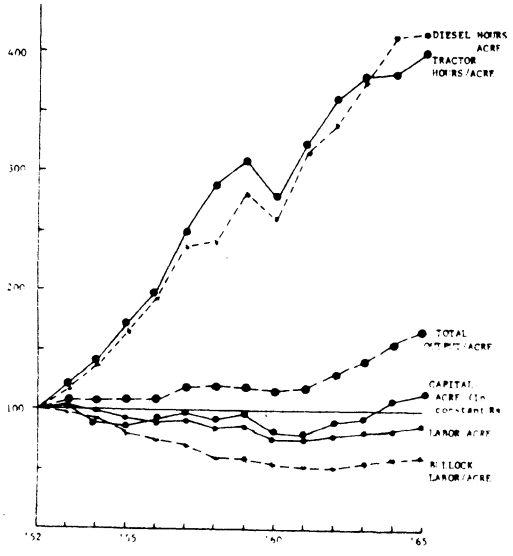


FIGURE 17: INDICES OF VARIOUS INPUTS PER CULTIVATED ACRE IN CENTRAL PUNJAB, 1952-65 (Base: 1952 = 100)

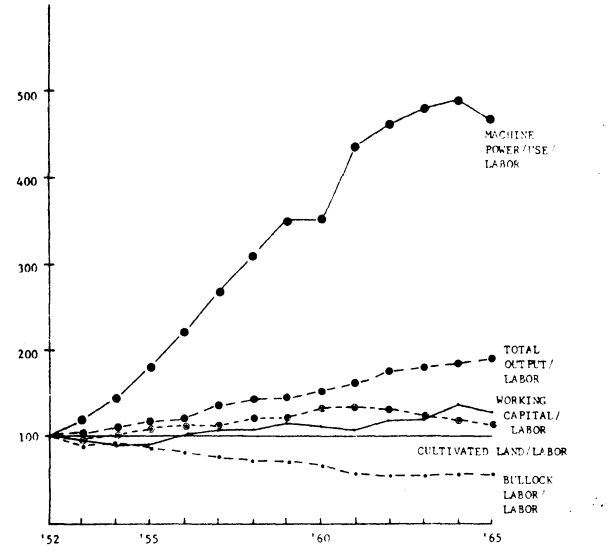


FIGURE 18: INDICES OF VARIOUS INPUT TO LABOR RATIOS IN CENTRAL PUNJAB, 1952-65 (Base: 1952 = 100)

output per cultivated acre increased, labor and bullock labor use per cultivated acre declined, total financial outlays showed a slight increase only after 1963, and the real increase was confined to an increase in the use of new power sources as evidenced by the increase in diesel and tractor hour use per acre.[12] Finally, as output per man day increased twofold and sales per man day increased threefold, the use of animal draft per man day declined, the use of mechanical power per man day increased over fourfold.

IV. MECHANIZATION IN A LABOR "SURPLUS" ECONOMY[13]

When we examine the changing factor proportions in this period we find three dominant features. First, an increasing proportion of the total inputs are being devoted to nonfarm variable inputs such as nutrients, fuel and water. Second, the real process of substitution has involved a choice in the use of power sources, with a displacement of traditional power sources (animal draft and unskilled labor) by mechanical power sources (tractors, diesel engines and electric motors and skilled labor). Third, the displacement has been task specific effecting a restructuring of labor utilization by season.

The adoption of new varieties associated with the use of yield increasing nonfarm inputs is far easier to understand and recommend for a "labor surplus" economy than the mechanization of specific agricultural tasks. Indeed mechanization in a labor surplus environment is something of a paradox that invites further analysis. What were the main factors responsible for this process and what are the main implications, especially for employment, if this process were to continue in the Punjab?

The three most important factors that explain the paradox are: (1) seasonal labor scarcity, (2) the requirement of timeliness for agricultural tasks, and (3) the cost effectiveness of mechanical technologies. First, the seasonal labor shortages identified by the model show that the Punjab was not a labor surplus economy. The apparent labor surplus was merely a mistaken reflection of the aggregation of the labor input over time. When we recognize that labor is heterogeneous not only with regard to skill, but also with regard to the time, so that we treat labor in each season as a separate input we conclude that labor is a "scarce factor". Attempts to economize on this factor by replacing a seasonally labor intensive technology by a seasonally labor saving technology are clearly "rational" in a purely economic sense. This is precisely why we observe task specific mechanization.

Our model results are independently substantiated by the existence of seasonal wage differentials, with wages for the harvesting, land preparation and irrigation tasks (tasks in which there has been mechanization) substantially higher than wages for which labor intensive technologies have been retained, as in the case of cultivation and weeding tasks. These data are shown in Table 1.

Second it is well known that agricultural operations and hence the derived demands for all factors in production are time inelastic. Unless factors are available at specific critical times they need not be available at all. In the period with the increase in total cropped area, due to increased double cropping, and increased intensity of land use due to increased water use, factors which were previously abundant became scarce at crucial times when they were needed. This has been true of labor and even more of power sources (both stationary and motive).

TABLE 1: WAGE RATES AND OPERATING COSTS FOR BULLOCKS AND TRACTORS* (Rs./Day)

Year	Labor I III[a]	Labor IV[b]	Labor II VII[c]	Labor V VI[d]	Bullock Labor[e]	25 HP Tractor (Rs./Hour)[f]	Ratio of Hourly Tractor/Bullock Cash Costs
1951	1.70	2.42	1.30	2.12	1.62	2.15	10.62
1952	1.78	2.42	1.42	2.26	1.57	2.12	10.80
1953	1.86	2.45	1.52	2.40	1.54	2.08	10.81
1954	2.01	2.37	1.69	2.56	1.40	2.07	11.83
1955	1.98	2.50	1.69	2.69	1.28	2.02	12.62
1956	1.98	2.50	1.75	2.62	1.41	1.98	11.23
1957	2.16	2.37	2.02	3.13	1.61	2.17	10.79
1958	2.29	2.51	2.03	2.51	1.52	2.36	12.42
1959	2.35	2.36	2.12	2.30	1.82	2.40	10.55
1960	2.45	2.20	2.37	2.40	1.63	2.41	11.83
1961	2.50	2.28	2.39	2.48	1.60	2.50	12.50
1962	2.59	2.61	2.60	2.80	1.60	2.54	12.70
1963	2.82	2.52	2.59	2.88	1.57	2.59	13.2
1964	2.89	2.91	2.93	3.61	1.83	2.90	12.68
1965	3.19	2.84	3.02	3.62	1.86	3.01	12.94

*Statistical Abstract of the Punjab, 1965 and I.J. Singh (1971, pp. 319-320).

a) plowing and sowing tasks, b) "other"tasks, c) the cultivation tasks, d) harvesting tasks, e) includes only the costs of purchased concentrates, excludes fodder, f) costs of fuel, oil, maintenance and repairs.

Studies in the early 1950's showed animal draft power to be a surplus resource in the Punjab.[14] However, during the transition described by the model increased double cropping and increase water use, which requires better land preparation and additional cultivation, caused a serious power shortage. In aggregate terms it appeared that animal draft could have been replaced by labor, but as we have seen there was a seasonal labor shortage too, so that for some tasks the only alternative was to increase investments in new mechanical power sources to overcome the power bottlenecks during certain crucial periods.[15]

Third, and perhaps the most important reason why mechanization occurred in the Punjab is because it was extremely profitable: new power sources are

so efficient in the performance of specific tasks that they overcome higher costs per hour of power use. Although the operating costs per tractor hour were ten to thirteen times greater than the cash costs per bullock hour (Table 1), this was offset by the fact that it requires ten to thirty times as many hours to perform the task by animal draft as it does by mechanical power sources. The latter fact is brought out in Columns 1 and 2 of Table 2. In addition, animal draft has to be fed even when not in use, and requires additional fodder when worked.[16] If we consider the variable fodder requirements when animals are worked in terms of the opportunity cost of the land required to grow the fodder, we see the overwhelming cost advantage of mechanical technologies over traditional technologies. This is shown in columns 3 and 4 of Table 2.

The cost effectiveness of mechanical technology is further reflected in the shadow prices on quasi-rents of various machine capacities estimated by the model as shown in Table 3. They demonstrate the high marginal value productivity associated with investment in labor saving technology.

V. CONCLUSIONS AND SPECULATIONS

The Punjab model has tracked the agricultural development in one LDC through a transition from traditional to modern technology in a way that shares many common characteristics with the process as it occurred elsewhere. It has displayed how, in spite of vaste institutional differences distinguishing them from their counterparts elsewhere, peasant farmers are amenable to economic incentives and respond rationally once appropriate account is taken of their decision milieux. It has shown that, in spite of continued belief to the contrary, traditional agriculture can develop rapidly within a framework of a

TABLE 2: REAL COSTS OF TRADITIONAL AND MODERN TECHNOLOGIES*

Task	Power Input Hours/ Standard Unit[a]		Fodder Costs Of Bullock Power	
	Bullocks	25 HP Tractor or 7.5 HP Motor	Acres Required Per ~~Acre~~ unit ~~Cultivated~~ Task	Opportunity Cost of Land Required for Fodder[c]
Land Preparation	22	1.375	0.0715	Rs. 95.81
Irrigation	31.2	1.700	0.1014	Rs. 135.88
Harvesting and Threshing Winter Crops	40.0	4.150	0.13	Rs. 174.2
Sugarcane Crushing and Gur Preparation	214.0	35.800	0.6955	Rs. 931.97
Transportation	5.0	0.250	0.0163	Rs. 21.84

*I.J. Singh, R.H. Day and S.S. Johl (1968) and I.J. Singh (1971).

[a]A standard land preparation unit is defined as 2 plowings and one planking; a standard irrigation is defined as 3 acre inches of water delivered; a standard harvest and threshing involves 10 quintals of output; a standard sugarcane unit is 100 quintals of cut and stripped cane and a standard transport unit is 10 quintals of produce transported an average distance of 2.5 miles to the market.

[b]Assuming a consumption of 0.65 quintals of green fodder per animal per work day and a fodder yield of 200 quintals per acre on irrigated land.

[c]Shadow price of rabi irrigated land was Rs. 1340/acre in model in 1965.

TABLE 3: QUASI-RENTS FOR VARIOUS MACHINE CAPACITIES

Year	Tractors Rs./Hr.		Tubewells Rs./Irrigation		Threshers	Tractor Transport Rs./Qt.	
	Period III	Period VII	Rabi	Kharif	Rs./Qt.	Rabi	Kharif
1952	139.4	50.9	159.5	47.7	*	2.84	4.77
1953	138.3	49.5	157.2	78.0	*	2.76	4.76
1954	147.9	65.1	168.8	89.6	*	3.17	5.18
1955	55.5	30.4	174.2	62.5	*	2.21	4.40
1956	51.2	26.7	68.6	57.1	*	2.09	4.18
1957	56.0	30.6	73.7	16.8	106.4	2.19	4.42
1958	62.9	35.0	83.3	18.5	100.2	2.40	4.91
1959	67.9	37.3	91.5	21.5	161.9	2.72	5.47
1960	72.3	43.6	97.2	20.4		2.94	5.58
1961	40.5	36.9	82.9	20.6	21.5	2.93	2.93
1962		32.5	28.9	21.2	21.9	2.77	2.77
1963	40.9	34.4	29.1	21.5	24.8	2.88	3.12
1964	75.0	33.6	30.9	22.1	4.8	2.81	5.98
1965	80.4	37.5	34.0	24.6	4.9	3.14	6.39

decentralized market oriented economy, given policies that facilitate appropriate developments outside the farm sector. The path of transformation was characterized by changing relative factor scarcities and proportions, the adoption of new mechanical and biological technologies and a steady increase in commercial in place of subsistence production.

Although this study has been concerned with the green revolution as it occurred in the Indian Punjab, its insights are more generally applicable. They indicate that the process of development involves the removal of particular strategic constraints as seen by the individual decision maker. Not only is his ability to respond to market incentives limited by these constraints, but their existence leads to a path of development perhaps dramatically different from that which would have been predicted by more aggregate analyses. Which constraints turn out to be crucial depends upon the particular case under consideration, but the "green revolution" package of water, chemical nutrients and new varieties would appear to offer hope of raising biological production functions in other regions with dramatic results. The concomitant effects on resource use, market linkages, technology and employment however depend upon the local situation, the specifics, which must be quantitatively pinpointed and incorporated into the analysis.

We have used the Punjab model to project the possible future development of the region to 1980, DAY and SINGH [1972]. Briefly, the model predicts that the trends displayed here will continue at an accelerated pace to 1980, that by then the region will have a true and not merely apparent surplus of farm labor, and that it will have reached a state of "maturity," of more or less complete commercialization and modernization.

Two possible implications may be important. First, the projected decline in labor demand for fixed crop production below the 1955 level coupled with continued population growth within the region could have serious implications for rural-urban migration. In this regard the development process in the Punjab seems to be reproducing some of the events of a similar transformation that occurred in the American South one or two decades earlier [DAY 1963, 1967]. If properly understood and anticipated the impact on employment and migration can perhaps be planned for in advance. Perhaps the social costs associated with the "long hot summers" in the U.S. could be avoided or reduced.

A second implication is the possible development of agricultural surpluses -- at least in the short run -- in the LDC's. Already huge quantities of wheat have piled up on railway sidings, burdening transportation and market networks. The strain of food grain surpluses on international markets is being felt. Could it be that India's farm problem, until now thought to be one of increasing output, could become, like that of the U.S. in past decades, one of maintaining farm income and price stabilization? Could it soon be that surpluses instead of deficits could come to plague and dominate domestic economic policy in a way thought inconceivable less than a decade ago? Again foresight and understanding can lead to better preparedness. What has been learned about the "farm problem" in the U.S. and policy endeavours to solve it, should provide a rich source of experience upon which the LDC's may soon have to draw.

NOTES

[1] The most prominent recent representative of this school is MYRDAL [1968]. For further references see DAY and SINGH [1971], note 4].

[2] SCHULTZ [1964]. BAUER and YAMEY [1959] were amongst the first of the studies that obtained this finding. For other references see DAY and SINGH [1971, note 5].

[3] The central five districts of Amritsar, Kapurthala, Ludhiana, Jullunder and Patiala were used for regional analysis to assure a regional aggregate that is fairly homogeneous with respect to soils, climate, topography, farm size, tenure conditions and resource distribution assumed by our model in the previous section.

[4] There is ample corroborating evidence on the trends in the use of non-traditional inputs [see A.S. KAHLON et.al. (1966) and W.E. HENDRIX and V. GIRI (1969)] and on the decline in the use of bullock labor [see A.S. Kahlon et.al. (1969)], and increased land and water use [see Economic and Statistical Organization: (1960,...,1969)], but less agreement about what has happened to total employment. Weelaborate on this issue later.

[5] For further substantiation also see W.E. HENDRIX and V. GIRI [1969, p. 175].

[6] One of the reasons for this discrepancy may be the fact that recorded investments in diesel cane crushers were carried out by few individual farmers who then perform this processing task as a separate enterprise. The model does not capture this because it concentrates on the investment behavior of cultivating households. For them, given that their family labor is a fixed resource, traditional bullock cane crushers become relatively unprofitable only when labor is seasonally scarce.

[7] Thus for example one observes fairly labor intensive tasks like hoeing and weeding and cutting and stripping of sugarcane and cotton picking still being performed by manual methods, alongside with other labor intensive tasks like irrigation and land preparation being performed by mechanical means on the same farm.

[8] Four major new crop varieties have become available to Punjabi farmers. They include hybrid maize (available in 1957), dwarf Mexican wheat (available by 1960), high yielding rice from the Taichung strains developed in the Philippines and hybrid bajra (millets) developed in India.

[9] In understanding these results several points should be borne in mind: 1) the yields shown are average yields (i.e., averaged over irrigated,

unirrigated and variety conditions); 2) chemical nutrients became available only in 1957 and their supply actually declined between 1958-1960; and 3) most new varieties (except maize) were available in the region only after 1960.

[10] Cash outlays on nonfarm produced capital goods included are outlays on the purchase of tractors, tubewells, and threshers, while outlays on nonfarm produced variable inputs included are outlays on chemical nutrients, fuel, and canal water charges. Total cash outlays include outlays on both nonfarm-produced inputs and farm-produced inputs including seeds, farm yard manures, concentrates for animal draft and wages of hired labor. All inputs are valued at constant 1952 prices.

[11] These results are amply borne out by examining the cash outlays of cultivating households in the sample survey data, as well as in the Farm Management studies. See Board of Economic Inquiry: Farm Accounts of ... Cultivators in the Punjab, 1950-51,..., 1967-68, and P.A.U.: Studies in the Economics of Farm Management, Ferozepur District, 1968-69.

[12] Independent evidence for these trends is contained in the farm management data compiled by the Department of Economics and Sociology, P.A.U., which shows bullock labor use per acre declining and tractor use increasing. That survey also shows labor use per cultivated and cropped acre increasing, a trend evident in our results after 1961. See S.S. JOHL [1971].

[13] Arguments in this section owe a great debt to continual discussions with S.S. JOHL and his thought provoking paper [S.S. JOHL (1971)].

[14] As in the case of labor, aggregation over seasons probably hid the true nature of the scarcity, a fact still uncorrected in recent studies.

[15] This aspect should have shown up as "tight" constraints on seasonal bullock labor in the model. However, these were all loose. See I.J. SINGH [1971A, p. 529]. These could have been due to either: i) an overestimation of the bullock capacities and ii) too aggregate a seasonal breakdown to allow the model to capture this effect (especially in the last week of October and the first week of November when summer crops are harvested and marketed and land has to be prepared for winter planting, all in a short span of two weeks. The model apparently failed to capture this because bullock labor constraints were aggregated for four weeks in the model. See SINGH op.cit. (p. 529)]).

It is for this reason that JOHL (op.cit.) argues, that in the period of transition, "mechanical power use may thus have some complementary effects on labor employment at the farm firm level," and that "due to power bottlenecks [the] adoption level of technological innovations may remain low," (p. 5), a point our results would seem to support. The long run effects on employment, however, are another matter.

[16] Draft animals are fed green fodder that is grown on rabi (winter) irrigated land in competition with wheat. With the introduction of high yielding wheat varieties and a secular increase in the price of foodgrains the opportunity cost of fodder, measured interms of the rental value of rabi irrigated land, has been continually rising. This is also predicted by the model as it shows the shadow price on such land increasing from Rs. 232 in 1959 to Rs. 1,340 in 1965.

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